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Review Article

# European riverine and coastal wetlands under pressure: biodiversity and climate change

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## Abstract

Although European coastal and riverine wetlands occupy a small share of the European land area, these ecosystems host remarkable biodiversity and provide a wide range of ecosystem services fundamental for human well-being, including clean water, recreation, food provision and climate regulation. Synthesising current knowledge across biogeographic regions, this review shows that only 12% of EU riverine and coastal wetland habitat types are in favourable condition, while the majority continue to deteriorate, mirrored by substantial declines in many wetland-dependent species. Climate-related impacts vary strongly across Europe and interact with existing human pressures such as land-use change, hydromorphological alteration, hydropower, coastal engineering and pollution, accelerating habitat and species loss and reducing the resilience of wetlands to climate change impacts. The paper calls for a rethinking of coastal and riverine wetlands as multifunctional landscapes and stresses the need for coordinated, cross-sectoral policy approaches. These wetlands are positioned not only as vulnerable systems but as pivotal Nature-based Solutions for achieving climate resilience and halting biodiversity loss, while remaining essential resources for human life support.

## Highlights

- Remaining European riverine and coastal wetlands are small and fragmented, yet vital for biodiversity and climate resilience.
- Only 12% of EU riverine and coastal wetland habitat types remain in favourable conservation status.
- Climate impacts vary regionally and interact with multiple pressures, demanding tailored adaptation strategies.
- Wetland multifunctionality makes them key Nature-based Solutions.
- Riverine and coastal wetlands must move from the policy periphery to the core of climate-biodiversity action, enabled by an integrated, cross-sectoral restoration and conservation effort.

**Key words:** Biodiversity loss, climate change impacts, coasts, ecosystem services, European wetlands, floodplains, Nature-based Solutions, wetland restoration

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## Introduction

Wetlands are among Europe's most biodiversity-rich and climate-relevant ecosystems, yet they have undergone extensive degradation over recent decades. Within this broad group, riverine and coastal wetlands form dynamic transition zones between land, freshwater and marine systems. They support unique species assemblages, provide key hydrological and biogeochemical functions, and contribute significantly to climate adaptation and climate change mitigation. These ecosystems are increasingly affected by multiple, interacting pressures, ranging from land-use change, river regulation, hydropower development, coastal engineering and pollution to the accelerating impacts of climate change, resulting in widespread losses of habitat quality and biodiversity. This synthesis provides a concise overview of the current status and climate-related challenges affecting European riverine and coastal wetlands and their associated biodiversity. Besides floodplains and coastal wetlands, mires, bogs and shallow peats represent another important wetland category in Europe. Depending on the biogeographic region, peat-forming habitats can also occur as characteristic components of river floodplains and coastal wetland complexes. Historically covering almost 10% of Europe's land area (Tanneberger et al. 2017), peatlands have suffered substantial degradation and losses, in many EU countries exceeding 50% (Tanneberger et al. 2021), due to exploitation for peat mining and later drainage for agriculture and forestry. As a result, drained peatlands have become major sources of greenhouse gas emissions (Giersbergen et al. 2024). However, peatlands deserve separate attention, as this review focuses primarily on European floodplains and coastal wetlands. Specifically, it addresses the following guiding questions: What is the current extent and condition of Europe's riverine and coastal wetlands? How do climate-related hydrological changes affect these systems across different European regions? What biodiversity trends are observed in major wetland-dependent taxa? How can riverine and coastal wetlands contribute to climate resilience? Considering the broader web of pressures that compound these challenges, what are the implications for wetland restoration and conservation? This overview serves as an introduction to the following articles in this Special Issue, which explore the value of wetlands and their Ecosystem Services (ES), their role as Nature-based Solutions (NbS), along with restoration opportunities and policy responses in more detail.

## European wetlands: small in area, big in impact and heavily damaged

The European continent hosts a rich variety of habitats. With its 66,000 km coastline and diverse geography, including major mountain ranges and lowland river systems, a wide variety of wetlands are supported (Verhoeven 2014). Historically rich in peatlands, floodplains and estuarine areas, Europe's wetlands host more than 90 habitat types under the European Habitats Directive (EU/92/43/EEC 1992), comprising mainly bogs and fens, rivers and floodplains, coastal and marine wetlands, estuaries and deltas, swamps and marshes, lakes and ponds, as well as human-made wetlands.

Wetlands, although small in area (see Box 1), play a disproportionately important role in forest- and agroecosystem-dominated landscapes, particularly in biodiversity conservation. They are hotspots for biodiversity, provide habitats for thousands of species of aquatic and terrestrial plants and animals, and are critical breeding, resting and feeding grounds for many, especially migratory birds (Gopal 2009). To take it globally, wetlands cover only 7% of the Earth's land surface, yet they hold most of the planet's accessible freshwater and provide essential habitats for ~40% of all known species (Wetlands International 2020). Beyond this, the impact of wetland health in Europe is felt globally, as healthy wetlands also serve as carbon sinks, sequestering carbon and playing a crucial role in mitigating climate change (Mitsch et al. 2012; Ludewig et al. 2026). More locally, they also play a vital role in adapting to the effects of climate change. Acting as natural sponges, they help regulate the water cycle by receiving and storing excess water during floods and slowly releasing it during droughts (e.g. Acreman and Holden 2013; Ferreira et al. 2023). Wetlands also provide a range of provisioning services: their ability to filter nutrients (see Zak et al. 2026) and trap pollutants makes them essential for maintaining water quality, benefiting both ecosystems and human use by supplying freshwater for drinking and irrigation, along with rice, fish and shellfish from fresh and coastal waters, as well as fibre and fuel (Ramsar 2018). For example, Bertassello et al. (2025) estimate that existing European wetlands remove 1,092 (± 95) kt of nitrogen per year (i.e. 6.7% of the current surplus) and that, in the absence of existing wetlands, the nitrogen loads would be ~25% higher. Beyond their ecological functions, wetlands hold deep cultural and spiritual significance by supporting traditional knowledge systems and fostering a sense of place and belonging (see Wantzen and Cao 2026). Moreover, they provide valuable spaces for recreation, contributing to our physical and mental health (Wood et al. 2024; Reimold et al. 1980).

Together, the overall value of these functions, known as Ecosystem Services (ES), which contribute to human well-being through food security, biodiversity support, water regulation, climate mitigation and recreation, is immense and far outweighs that of terrestrial ecosystems (de Groot et al. 2012; Ramsar 2021a; Jähnig et al. 2022; Day et al. 2024; Stammel et al. 2026). Davidson et al. (2019) estimate that the global monetary value of wetland ES is about USD 47.4 trillion per year; that is 43.5% of the value of all natural biomes for a much lower coverage rate (see above). They also estimate that coastal wetlands, representing only 15% of global wetland area, deliver 43.1% of this value.

Although wetlands still cover a global area larger than Canada, they have been rapidly declining. Estimates of global wetland loss vary widely due to methodological differences and diverging definitions. For decades, high estimates of wetland loss have been reported in the scientific literature, with claims that up to 50% of the world's wetlands have been lost since 1900 (Zedler and Kercher 2005). More recent assessments based on regional extrapolations and geospatial overlays suggest net losses ranging between 33% and 57% since 1900 (Davidson et al. 2020; Hu et al. 2017). Fluet-Chouinard et al. (2023) provide a comprehensive estimate, focusing on inland wetlands, coastal intertidal zones and nearshore marine wetlands. Their findings indicate that natural wetland areas have declined by ~3.4 million km$^2$ since 1700, corresponding to a 21% loss.

North America, Europe, Central Asia, India, China, Japan and Southeast Asia have been identified as hotspots of wetland loss (Fluet-Chouinard et al. 2023).

In Europe, over the past 250 years, wetlands of all types have been extensively drained, altered and reclaimed, primarily for agriculture, urban development, flood control and transportation, resulting in significant degradation or loss of their ecological functions (Junk et al. 2012). Reported estimates vary significantly across regions, ranging between 45% and 80%, with wetlands in northern Europe generally less affected than those in central and southern regions (Hu et al. 2017; Verhoeven 2014; Fluet-Chouinard et al. 2023). In northern Europe, drainage was largely linked to peat extraction and timber logging, while losses in central and southern regions resulted mainly from river straightening and agricultural conversion (e.g. Blackbourn 2007; Hohensinner et al. 2013; Fluet-Chouinard et al. 2023). Similar to current wetland extent estimates (**see** Box 1), discrepancies in reported wetland loss can be attributed to differences in calculation methods, including varying definitions of wetland degradation, which range along a continuum from complete drainage and land conversion to altered hydrological conditions and soil degradation. The precise quantity of wetland loss in Europe over the past centuries remains uncertain.

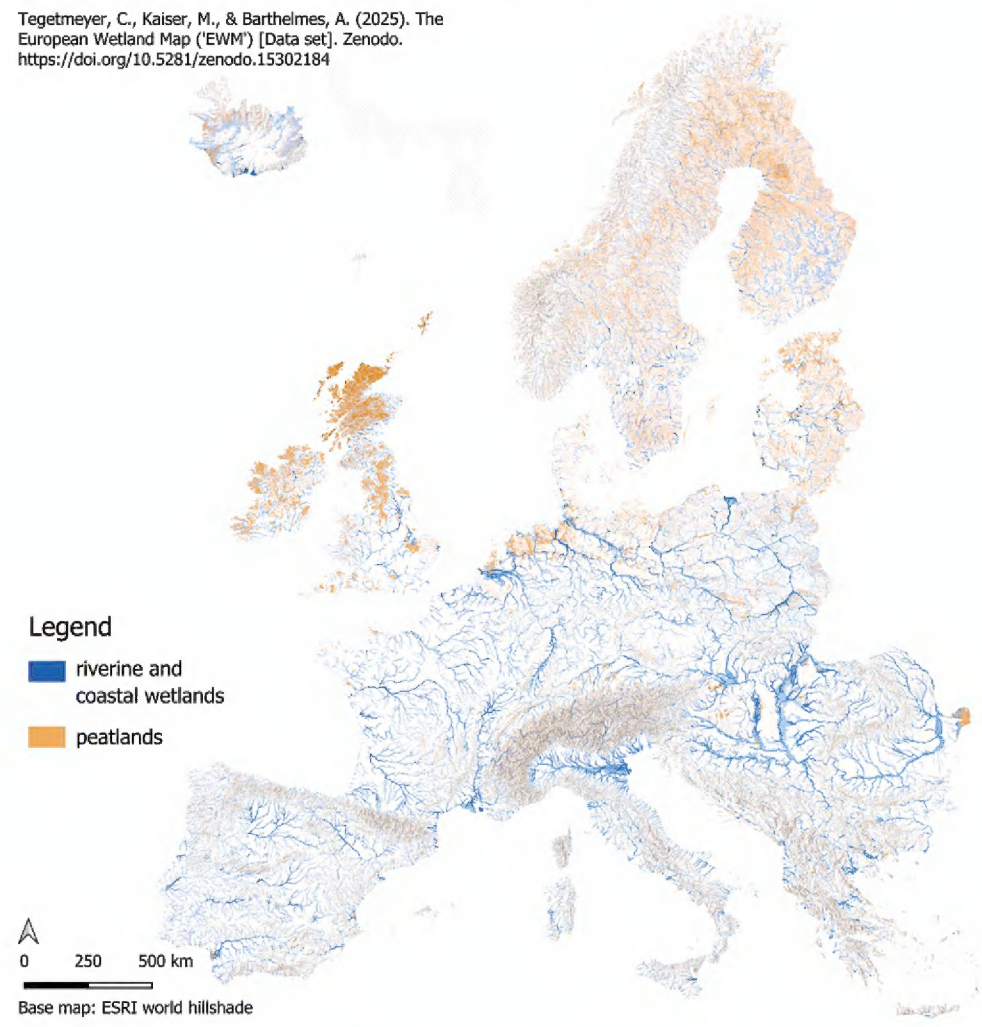
In large river floodplains, the flood pulse was historically unpredictable and often occurred during the growing season, threatening crops and livestock (Tockner et al. 2000). This unpredictability hindered flood-adapted management and led to the construction of dikes for flood protection, such as the straightening of the Rhine River by engineer Tulla in 19$^{th}$-century Germany (but also along the Danube, the Rhône and many other large European rivers; Petts 1987; Hohensinner et al. 2013; Tockner et al. 2022). The fluvial network is also modified by more than 1.2 million instream barriers in 36 European countries, corresponding to a mean density of 0.74 barriers per kilometre (Belletti et al. 2020), and less than 23% of large European rivers are still free-flowing (Grill et al. 2019). Due to their reliance on specific environmental conditions, especially hydrology, floodplains are particularly vulnerable, and even minor changes, such as small fluctuations in water levels, can have major consequences, for example, for water-dependent vegetation (Maltby 2009). Lastly, land-use changes deeply modify the integrity of riverine wetlands. Based on the Copernicus Land Monitoring Service (2021), it is estimated that only 30% of riverine zone areas across Europe are still forested, whereas they could exceed 95%. Obviously, there are differences between countries: the rate can reach an average of 50% in Scandinavia and fall to 10% in England and Ireland. Moreover, between 2012 and 2018, ~9,000 hectares disappeared each year in Europe. Nearly 50% of these areas were reallocated to built-up areas, 25% to cultivation and 25% to grazing. As a result, only small areas of near-natural floodplains remain today, and 70% to 90% of floodplains in Europe are disconnected from characteristic flooding dynamics (EEA 2020a), even though the magnitude and mix of pressures vary across regions. For example, in Scandinavian floodplains, agricultural land-use pressure is lower than in much of the rest of Europe (Weissteiner et al. 2016), but extensive hydropower development has fundamentally altered river flows, fragmented channels and degraded floodplain and delta ecosystems (Renöfält et al. 2009). Whereas in western, central and southern Europe, land conversion, regulation and dams are combined.

**Box 1.** European coastal and riverine wetlands – definitions and extent.

As the term itself suggests, wetland is an umbrella term for ecosystems whose formation, functioning and characteristics are primarily shaped and influenced by water. There is no single, universally applicable definition of wetlands, which has led to a variety of definitions and classification systems (Čížková et al. 2011, EC 2020a). For example, wetlands can be categorised based on the sources of their water supply. **Coastal wetlands**, influenced by ocean tides, appear as tidal wetlands; **floodplains/riverine wetlands** are primarily shaped by river waters; and estuaries result from a mix of both. Additionally, wetlands may form from groundwater sources, such as springs and fens, or from precipitation and snowmelt, which give rise to bogs and ponds (Keddy 2010).

One of the most widely recognised definitions is provided by the Ramsar Convention (1971), which describes wetlands as "*[...] areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.*" (Ramsar 1971).

This definitional variability also affects the estimation of the total extent of wetlands globally and in Europe, as figures vary depending on the classification applied. Moreover, differences in the spatial reference for Europe, whether considered geographically or as EU Member States, and in the data sources used influence the resulting percentages. Therefore, estimates vary between 500,000 km$^2$, corresponding to 7% (Nivet and Frazier 2004), 174,400 km$^2$, corresponding to 4.5% (EC BISE 2023), and 73,000 km$^2$, corresponding to 1.7% (EC Eurostat 2018). However, according to a new European Wetland Map (EWM) launched on World Wetlands Day 2025 (Tegetmeyer et al. 2025), the total wetland area, including floodplains, coastal wetlands, other wetlands and peatlands, sums to ~77,079 km$^2$, corresponding to 1.5% of the European land surface (details in Tegetmeyer et al. 2024). When peatlands are excluded, this figure drops to 0.75%, as illustrated below by a map compiled from the EWM dataset, which visualises several riverine and coastal wetland types and includes peatland areas shown in a distinct colour scheme.


Tegetmeyer, C., Kaiser, M., & Barthelmes, A. (2025). The European Wetland Map ('EWM') [Data set]. Zenodo. https://doi.org/10.5281/zenodo.15302184
Legend
riverine and coastal wetlands
peatlands
0
250
500 km
Base map: ESRI world hillshade

Resolution and accuracy are strongly constrained by the quality and completeness of the underlying datasets. Due to widely varying mapping scales, divergent national definitions and heterogeneous recording methods, compiling a harmonised European dataset remains highly challenging. As a result, the presented map (see above) deviates substantially from the actual wetland distribution in many regions. Nevertheless, the EWM represents an important step forward, as it is the first integrated, Europe-wide wetland map produced from multiple open-access datasets, even though the individual layers have been publicly available previously. Its remaining inaccuracies underline the urgent need to further harmonise mapping standards and improve data quality across Europe. None of the datasets used for the EWM provides an ecological status assessment. For floodplains, evaluations show that in Germany 70–90% of active floodplains have been lost, and only about 10% of the remaining areas are in good condition (Koenzen et al. 2021), consistent with Europe-wide findings by Globevnic et al. (2020). Most coastal wetland habitats in the EU are in poor ecological condition, or data are insufficient to reliably assess their status. For peatlands, the most recent European assessments are provided by Tanneberger et al. (2021) and Giersbergen et al. (2024).

For coastal wetlands, population pressure is a significant driver affecting these ecosystems at both global and continental scales (Day et al. 2024). Indeed, 41% of the EU population lives in Europe's coastal regions (EEA 2020b). Coastal wetlands were extensively converted into polders for pasture and cropland, exemplified by the Wadden Sea region in northern Europe, where poldering began in the sixteenth century and ceased in 1954, with the remaining Wadden Sea area now partly protected. However, many other European coastal wetlands also face heavy pressures. In the Mediterranean, areas such as the Camargue in France, the Doñana wetlands and Ebro Delta in Spain, and the Po Delta in Italy are threatened by urban growth, intensive agriculture, water management changes, pollution and infrastructure development. The Danube Delta in Romania and Ukraine, one of Europe's largest wetlands, is also subject to similar pressures.

## European riverine and coastal wetlands in a changing climate

European riverine and coastal wetlands are affected by multiple long-standing anthropogenic pressures outlined above. These pressures continue today and are further intensified by climate change, which not only influences the functioning of wetlands but also accelerates the release of greenhouse gases from degraded wetlands (IPCC 2023a) and reduces their capacity to buffer climate-related impacts. The most evident and direct effects of climate change on riverine and coastal wetlands can be broadly grouped into those caused by (1) rising average temperatures, (2) changing precipitation patterns, and (3) the increasing frequency and intensity of extreme weather events – each with regionally and ecologically specific consequences.

Average climate conditions are expected to continue shifting significantly over the coming decades. As predicted by the Intergovernmental Panel on Climate Change (IPCC), rising temperatures and global warming will lead to sea-level rise and an increase in extreme weather events (IPCC 2023a). This holds true for Europe as well. Recent trends and future projections for Europe have been inventoried and synthesised in several scientific summaries. According to the European Environment Agency's report, which draws on peer-reviewed models, datasets and literature, trends in temperature, precipitation and climate extremes, including heatwaves, droughts, heavy precipitation and floods, are projected to intensify across Europe in the coming decade (EEA 2024a). The growing intensity and frequency of extremes will strongly affect riverine and coastal wetlands, as they are highly dependent on the hydrological cycle. Their sensitivity to changes in water quantity and quality, driven by altered hydrological regimes, makes them highly vulnerable to climate change (Erwin 2008; Harris et al. 2018; Moomaw et al. 2018). As hydrological patterns shift, many local water regimes are becoming wetter or drier. For example, in snow-affected catchments (Central Europe and Eastern Europe), high flows are expected to appear earlier in the year, and the duration and volume of inundation are projected to decrease (Schneider et al. 2011; Fink et al. 2026). This hydrological regime change is likely to lead to a reduction in habitat for several taxa (fish, vertebrates, water birds and floodplain-specific vegetation) and thus to a loss of biodiversity, floodplain productivity and fish production. However, contradictory results have been reported in Spain, France, southern

England and the Benelux countries due to uncertainties in climate modelling for specific seasons. A shift in the water balance towards increased evaporation caused by warmer and longer summers not only leads to increased water loss in wetlands but also reduces the amount of water they receive from surrounding catchments, leading to degradation and loss of both riverine and coastal wetlands (Erwin 2008). Extreme events can impact species and habitats, leading to changes in species richness and composition (Ilg et al. 2008; Harris et al. 2018; Fink et al. 2026). In riverine systems, extreme droughts can affect the total growth frequency of plants and may cause shifts from freshwater- toward salt- or drought-tolerant species, while extreme flooding will reduce the total area of wetland vegetation and lower vegetation diversity (Xiong et al. 2023). In coastal wetlands, severe storm surges, erosion events and prolonged inundation can lead to vegetation dieback, reduced sediment accretion and loss of habitat complexity. Thus, the physical impacts of climate change drive biological changes, including shifts in ecosystem structure, species distributions and abundance, altered phenology and physiology, and increased presence of invasive species (Moomaw et al. 2018). These changes can become long-lasting or irreversible if repeated extreme events occur and may lead to completely new biocoenoses (Hobbs et al. 2006). In recent decades, extreme biological responses to individual extreme weather events have already been observed in many ecosystems around the world (Harris et al. 2018). These changes also impair ecosystem functions and reduce the provision of key ES. Some of these important ES may even turn into disservices. For instance, instead of filtering and purifying water, wetlands may start to release stored nutrients, or when the rate of decomposition surpasses that of primary production (photosynthesis), wetlands may shift from acting as carbon sinks to becoming carbon sources (Salimi et al. 2021). The impacts of future climate scenarios on ES provided have been estimated by Okruszko et al. (2011) based on a sample of one hundred large wetlands in Europe and several ES (biodiversity, biomass production, nutrient removal, carbon storage and fish production). They anticipate a loss of between 26% and 46% of all identified ES by 2050. Moreover, the most significant loss of ES is expected to occur in Central Europe. Thus, as wetlands degrade, their ability to purify water, regulate floods, support biodiversity and provide resources such as fish and other harvestable goods is diminished (MEA 2005). These processes apply to both riverine and coastal wetlands, although the mechanisms differ (e.g. drying and disconnection in riverine systems and erosion and salinity intrusion in coastal systems).

Besides these direct impacts of climate change on ecosystem functioning, including changes in community composition and habitat change, wetlands are also affected by indirect pressures arising from changing water and land uses. Climate-change-induced decline in water quality, along with changes in the seasonality and extremity of river hydrology and threats to coastal wetlands from sea-level rise, storm surges and saltwater intrusion, require not only species and communities to adapt to these new conditions. Such changes often trigger management responses, such as strengthened technical flood protection, construction of weirs in the river itself or reservoirs to bridge droughts, resulting in additional water and land-use competition and further destruction of habitats or key site characteristics (EC 2020a; EEA 2018). An illustrative example is the surge in planned hydropower projects across the Balkans, an area identified

as a major freshwater biodiversity hotspot in Europe (Carrizo et al. 2017). Although promoted as a contribution to energy decarbonisation, these projects pose substantial risks to riverine ecosystems and wetland connectivity due to cumulative ecological impacts and disruptions of catchment-scale processes (Carolli et al. 2023). The expression of climate change impacts varies between European regions, and as wetlands are diverse in type and spread across different climatic zones, their responses to climate change will vary accordingly (Čížková et al. 2011; BMU et al. 2020).

In **coastal wetlands** (see Ibáñez et al. 2026), sea-level rise is expected to be the primary driver of change, particularly along the Atlantic coast (Čížková et al. 2011). Approximately 10% of the world's population lives in areas less than 10 metres above sea level (McGranahan et al. 2007), many of which are economically important regions such as river deltas. Given this, the most immediate and severe impacts of inundation through sea-level rise, accompanied by habitat loss and socioeconomic disruption, are expected to occur in these low-lying coastal areas (FitzGerald et al. 2008). Under high-emission scenarios, projections suggest that between 20% and 90% of today's coastal wetland areas could be lost by 2100, depending on the magnitude of sea-level rise and the region's capacity for inland migration (Schuerch et al. 2018; Spencer et al. 2016; IPCC 2023b). As the ability of coastal wetlands to shift landwards in response to rising sea levels is often prevented by human-made structures (a phenomenon known as "coastal squeeze"; Doody 2013), and sediment supply is disrupted, coastal vulnerability is further exacerbated. For example, in Denmark, extensive dikes, seawalls and other infrastructure prevent the natural inland migration of wetlands. A recent nationwide analysis (Canal-Vergés et al. 2024) predicts that by 2120, almost half (45%) of all Danish coastal wetlands will be permanently inundated under a medium sea-level rise scenario. In the Mediterranean countries, including France, a study by Verniest et al. (2024) found that by 2100, one-third to more than half of the > 900 analysed coastal wetlands could be submerged.

**Southern Europe** is, in addition to the challenges posed by sea-level rise, generally expected to face the greatest challenges from water shortages and intensifying competition for water resources among agriculture, industry, settlements and nature conservation efforts, including wetland protection (Čížková et al. 2011). Even under moderate emission scenarios, droughts are projected to become increasingly frequent and severe, especially in the southern and western parts of Europe (EC 2020a). Under high-emission scenarios, summer drought frequency in the Mediterranean could rise by up to 40% by 2100 (Spinoni et al. 2017), and under a 3 °C warming, absolute drought damages in the Mediterranean subregion are expected to quintuple, far exceeding those in northern Europe (EC 2020a). Although overall precipitation in the Mediterranean region is projected to decrease, heavy rainfall events are expected to become more frequent and intense, particularly in northern areas, raising the risk of flash floods in vulnerable coastal zones such as Turkey, Greece, Italy, France and Spain (MedECC 2020).

In contrast, **northern (boreal) Europe** is projected to experience a small but sustained decrease in droughts, a trend expected to continue under future warming scenarios (EEA 2021). While most of southern Europe is expected to see a decrease in annual precipitation, northern Europe is projected to

experience the opposite trend. However, even with increased precipitation, warmer temperatures accelerate microbial decomposition and seasonally dry surface layers. These effects mainly destabilise the wetland types dominant in this region, floodplains with mainly organic soils, bogs and fens, which have historically been important for storing vast amounts of carbon, relying on waterlogged, low-oxygen conditions. Warmer conditions also increase the risk of peat fires and permafrost thaw, further altering their hydrology and species composition (Turetsky et al. 2020). This shift threatens to turn these once-stable, mainly peat-rich wetlands from long-term carbon sinks into net sources of greenhouse gases, accelerating the climate change feedback loop (Harenda et al. 2017). However, changes in snowmelt timing, runoff seasonality and increased winter rainfall also affect riverine and coastal wetlands, altering hydrological regimes and water levels. Thus, in addition to the large-scale destruction caused by drainage, hydropower, forestry and land-use changes, warming and its accompanying effects will have profound impacts on biodiversity, water quality and the global carbon budget (Salimi et al. 2021).

**Central and Western Europe** are likely to be among the regions most affected by extreme weather events and their consequences, such as heavy rainfall followed by flooding (Čížková et al. 2011). Precipitation-driven river flood hazards in Western and Central Europe have already grown by ~11% per decade from 1960–2010 and are projected to rise further, by roughly 10% at 2 °C global warming and ~18% at 4.4 °C (Bednar-Friedl et al. 2022). These changing precipitation regimes also imply more severe summer droughts. Hotter summers, with higher evapotranspiration, are drying soils and reducing snow and glacier melt inputs, making rivers more dependent on rainfall. Alpine snowmelt-driven summer floods are expected to decline at ~2 °C warming, whereas winter and spring floods are expected to increase due to heavier rainfall and earlier snowmelt (Bednar-Friedl et al. 2022). Given the high population density in these regions, rising flood risks may fuel political pressure for hard flood-defence measures, potentially to the detriment of wetland hydrology and ecological functions if NbS are not prioritised.

It is worth noting that a major challenge, both scientific and applied, lies in the ability to account for the multiple pressures that interact. In fact, climate change, beyond its individual effects, is adding additional pressure to environments that are already subject to many pressures in terms of both water quality and quantity. This multi-pressure context is (1) still poorly taken into account (see Martínez-Megías and Rico 2022) and (2) a challenge because the pressures are not just added but combine in very complex ways (see Stella and Bendix 2019). Neglecting the impact of multiple pressures can lead to maladaptation, such as the construction of hard flood defences that disrupt lateral river floodplain connectivity. Even amid uncertainties, Nature-based Solutions (see 3.2.) must become central to climate resilience planning.

This complexity also applies to climate models predicting wetland responses. Climate change will significantly alter European freshwater wetland distributions (Schleupner 2011), but despite advances in climate modelling, considerable uncertainty remains, particularly regarding local hydrological impacts on floodplains and coastal wetlands. Downscaling global or regional climate models to site-specific conditions is challenging due to complex interactions between climate variables, hydrology and land use (Marchi et al. 2020).

Most large-scale models and drought indices (e.g. the Wetlands Drought Index) are primarily precipitation-driven and are not calibrated for the unique hydrological regimes of wetlands in general, often failing to account for river discharge, groundwater dynamics, capillary rise and local land-use interactions (Copernicus Global Drought Observatory 2024). While these tools offer standardised, globally applicable monitoring, they risk misrepresenting conditions, particularly where wetlands are buffered by deep aquifers or are highly sensitive to even minor hydrological changes. Addressing these gaps will require the development of wetland-specific monitoring and modelling frameworks that integrate local hydrological data, land use and climate projections, ensuring more accurate predictions and effective adaptation strategies (Acreman et al. 2007).

## European riverine and coastal wetlands biodiversity in decline

The full diversity of all (healthy) wetland types represents a significant reservoir of biodiversity, playing a crucial role in sustaining species richness and ecological resilience. Biodiversity is not only of intrinsic ecological value but also fundamental to human well-being (MEA 2005). Functional species assemblages maintain water purification, nutrient retention, carbon sequestration, coastal protection and flood mitigation, and many wetlands support fisheries, grazing systems and cultural landscapes. Many endemic species occur exclusively in specific wetland areas (Ramsar 2018). It is estimated that ~40% of the world's plant and animal species are dependent on wetlands, including 30% of all known fish species (Ramsar 2021b; UNFCC 2018). This global significance is equally evident in Europe. For example, a local study conducted at thirty sites covering just 7.2 $km^2$ (i.e. 0.0013% of France's land area) in the alluvial plain of the Adour in south-western France identified almost 1,500 plant species, representing around 15% of the French flora (Tabacchi and Tabacchi 2007).

Riverine and coastal wetlands represent a significant ecological niche, providing habitat for numerous threatened amphibians and reptiles, hosting migratory and resident water birds, and sustaining thousands of plant species. This is linked to (1) their unique conditions compared to surrounding terrestrial areas, such as flatter topography and distinctive hydrological regimes, allowing specialised species to thrive; (2) their high local variability in space and time, creating numerous ecological niches; and (3) the diverse array of wetland types, each supporting distinct assemblages of species (Sabo et al. 2005; Junk et al. 2006; Keddy 2010; Ramey and Richardson 2017).

As they are tightly coupled to hydrological and coastal dynamics, the human- and climate-related changes outlined in the previous sections are already translating into measurable biodiversity impacts across Europe's riverine and coastal wetlands. Water birds, for example, are facing multiple pressures associated with climate change, such as sea-level rise, temperature fluctuations and altered precipitation patterns, all of which are expected to drive significant habitat loss. Across Europe, ~45% of waterbird populations along the Africa–Eurasia flyway show declining trends (Wetlands International 2025), highlighting the sensitivity of wetland-dependent species to climate-driven hydrological change. In the Ebro Delta, species distribution models project that up to 70% of water bird habitat could disappear by 2100 due to rising sea levels (De la Cruz and Numa 2024). Similar patterns are observed in other

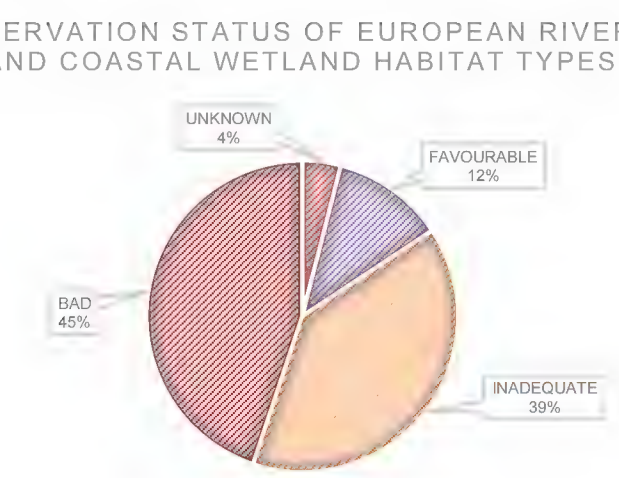
wetland-associated taxa. Migratory European freshwater fish populations have declined by 75% in recent decades due to habitat loss and fragmentation. This has been driven largely by the conversion of wetlands for agricultural use, hydropower development and the lack of free-flowing rivers, with more than 1.2 million anthropogenic barriers in European rivers (Belletti et al. 2020; WWF 2024; Stoffers et al. 2026). Amphibian data reinforce these trends across European wetlands. Amphibians, which are highly dependent on shallow aquatic habitats, show some of the most profound declines. Nearly one third of species are currently considered threatened in Europe. An additional 8% are categorised as Near Threatened. Priority conservation challenges identified in recent assessments emphasise anthropogenic pressures that have intensified over the past decade. Central among these are the spread of invasive species, the emergence of pathogens such as chytrid fungi, and increasing levels of chemical and nutrient pollution, all of which affect small water bodies and other amphibian breeding sites. Habitat destruction and degradation remain pervasive, particularly the loss of structurally complex aquatic habitats that support both adult and larval stages. These patterns highlight the disproportionate vulnerability of amphibians to hydrological disturbance and habitat fragmentation within wetland systems. Invertebrate data reveal similar patterns. Recent assessments of European dragonflies and damselflies (Odonata) highlight that ~21% of the 146 species assessed are threatened, with an additional 12% classified as Near Threatened (De Knijf et al. 2024). These taxa are particularly vulnerable to a range of anthropogenic pressures. Populations are threatened or destroyed by increased water abstraction, especially for agricultural use; water pollution combined with elevated nutrient loads; channelisation; gravel extraction; and the widespread use of pesticides and herbicides (De Knijf et al. 2024).

These indicators, demonstrating a decline across multiple taxa in European riverine and coastal wetland biodiversity, are also mirrored globally. Since 1970, populations of inland wetland species have decreased by 81%, while coastal and marine wetland species have seen a 36% decline (Ramsar 2018). The decline of species is closely mirrored by the degradation and loss of the habitats on which they depend. An overview of habitat trends provides essential context for interpreting the species-level declines described above and underscores the scale of conservation action required (Box 2).

In conclusion, the dominance of inadequate and bad conservation statuses across European coasts and floodplain habitats (see Box 2) points not only to a severe and ongoing decline in biodiversity but also to a weakening of the very functions that enable wetlands to buffer climate impacts. Climate change accelerates biodiversity decline through altered hydrology, extreme events and rising temperatures, while biodiversity loss, in turn, reduces wetlands' capacity to regulate floods, store carbon, and dissipate wave energy. For example, coastal wetlands can reduce wave energy by up to 60% (Möller et al. 2014), meaning that degradation of marsh or saltgrass habitats directly diminishes natural coastal protection. Similarly, structurally degraded floodplains store less floodwater and stabilise banks less effectively, reducing resilience to hydrological extremes. These dynamics illustrate that biodiversity not only responds to climate change but also actively shapes the extent to which wetlands can mitigate its impacts.

**Box 2.** Analysis of the status of European riverine and coastal wetland habitat types.

This overview draws on EU Member States' conservation status assessments (2013–2018). Annex I of the European Habitats Directive (EU/92/43/EEC 1992) lists 233 habitat types of European importance. The European Environment Agency (EEA) classifies 82 of these Annex I habitat types as wetland-related, including coastal, freshwater, peatland and riparian habitats, defined largely by their plant species composition. For the analysis of riverine and coastal wetland habitat types, six habitat categories were identified: (i) coastal and halophytic habitats, (ii) dunes, (iii) grasslands, (iv) freshwater habitats, (v) bogs and mires, and (vi) forests, including only those habitat types that occur naturally within floodplain or coastal wetland complexes (see Appendix 1 for the detailed list).




A detailed examination of the Annex I habitat types can facilitate an understanding of the current status of riverine and coastal wetlands in Europe. The conservation status assessments of European coastal and riverine wetland habitats show that the vast majority are in bad or inadequate ecological condition. Only 12% of the assessed habitat types are classified as favourable, whereas 39% are inadequate and 45% are in a bad conservation status. This finding suggests not only widespread degradation across Europe's biogeographical regions but also that many habitats are failing to meet minimum ecological requirements for maintaining biodiversity and ecosystem functioning.

These results align with broader assessments of ecosystem condition across Europe, where wetlands remain among the most threatened ecosystems (EEA 2020c). Notably, riverine and coastal wetlands perform worse in comparison with the average across all Annex I habitat types (36% bad, 45% inadequate, 15% favourable). The poor conservation status of these wetland habitats reflects how severely these ecosystems are threatened, fragmented and reshaped by human activities, with climate change-related pressures such as changes in precipitation and discharge, rising temperatures and rising sea levels further weakening key ecological processes (EC 2020c). The loss of habitats, their species and ecological functions directly reduces the capacity of these wetlands to support human societies, as these functions sustain the wide range of ecosystem services essential to human well-being, including water purification, flood regulation, shoreline protection, carbon storage, food provision, and recreational and cultural values.

This reciprocal relationship creates a reinforcing cycle of vulnerability. Breaking this cycle requires restoring wetland habitats, improving ecological connectivity and reducing anthropogenic pressures, particularly in regions where habitats are in poor condition. Reconnecting rivers and their floodplains and restoring coastal wetlands are essential steps to restore ecological integrity and secure climate resilience (EEA 2024b). Ultimately, separating climate and biodiversity policy frameworks risks undermining progress on both agendas. Addressing these crises in an integrated manner is therefore essential, and the restoration of wetlands provides a prime example of an intervention that simultaneously mitigates climate impacts and halts biodiversity loss.

## Mitigation and adaptation: wetland-based opportunities for climate resilience

Climate regulation, as well as the role of wetlands in buffering the effects of climate change, is identified among the key Ecosystem Services (ES) provided by all kinds of wetlands (Moomaw et al. 2018). Consequently,

restored wetlands can be essential components of climate change adaptation and mitigation strategies (Erwin 2008). While adaptation focuses on climate change impacts by enabling communities and ecosystems to adjust to present or anticipated effects, thereby enhancing resilience, mitigation targets the root causes of climate change by reducing greenhouse gas emissions (Kaden et al. 2023).

Coastal and riverine wetlands provide essential services that support **climate adaptation** to various hydroclimatic challenges. Their capacity to buffer environmental variability is determined by their hydrological connectivity, landscape position and biogeochemical processes, making them critical components of nature-based adaptation strategies (Capon et al. 2013; Junk et al. 2012; Fuller et al. 2022). In the context of increasing frequency and intensity of freshwater floods, floodplains attenuate peak flows by retaining floodwaters, thereby reducing the magnitude of downstream flooding (Acreman and Holden 2013). Thus, wetland restoration actions (e.g. blocking drainage, avoiding the removal of aquatic vegetation) can mitigate part of the current effects of climate change (Berezowski et al. 2018). Acting as natural sponges, riverine wetlands modulate hydrological extremes through water retention and gradual release of stored water during dry periods, contributing to the regulation of flow regimes and recharge of groundwater aquifers (Granata and Di Nunno 2025), thereby also improving water quality. For example, the Dutch “Room for the River” programme, involving various interventions (levee setbacks, side-channel deepening and floodplain area expansion), effectively reduced flood risk during extreme events, safeguarding urban infrastructure while enhancing ecological connectivity (Klijn et al. 2018). Wetlands International (2022) synthesises the broader climate-adaptation contributions of wetlands, which extend beyond flood control. For riverine wetlands, these include drought resilience through baseflow maintenance and aquifer recharge, buffering seasonal runoff variability in snow- and glacier-influenced catchments by retaining high-flow pulses, and releasing water during dry periods. Coastal wetlands contribute differently but complementarily. In addition to protection against storm surges, they support sea-level rise adaptation through land accretion and the protection of fishery and freshwater resources. Coastal wetlands also play a role in preventing saltwater intrusion and coastal storm defence by dissipating wave energy and supporting community recovery after extreme events. Approaches such as coastal realignment strategically restore wetland buffers to strengthen these protective functions (see de la Vega Leinert et al. 2026).

Next to riverine and coastal wetlands being key Nature-based Solutions for climate adaptation, they are also integral to **climate change mitigation** by acting as long-term carbon sinks that store large amounts of atmospheric carbon (Mitsch et al. 2012; Were et al. 2019; Ludewig et al. 2026). For example, globally, tidal wetlands accumulate about 53.65 Tg C $yr^{-1}$ (95% CI: 48.52–59.01) (Wang et al. 2020). Carbon sequestration takes place when plants fix atmospheric $CO_2$ via photosynthesis and then transfer that carbon into biomass and, ultimately, into soils, where it accumulates over time as carbon stocks (Were et al. 2019). Carbon stocks, sequestration rates and the nature of the responsible processes vary by ecosystem type, leading to a functional classification of carbon pools (Abdul Malak et al. 2021). In this context,

referring to the role of carbon in climate change mitigation via sequestration, many studies have focused on blue carbon, which refers to carbon stored in coastal and marine ecosystems such as salt marshes and seagrasses, or green carbon, carbon sequestered by terrestrial ecosystems. However, teal carbon, describing carbon accumulated in freshwater wetlands, has only recently entered the carbon colour nomenclature (Zinke 2020). Assuming total European wetlands cover around 370,000 $km^2$ (~7% of EU-27 + UK), Abdul Malak et al. (2021) estimate vast carbon stocks, between 12 and 31 Gt $CO_2$-eq, equivalent to 3–8 years of regional greenhouse gas emissions, and sequestration rates between 24 and 144 Mt CO2-eq per year, offsetting 1–4% of current annual emissions. The European wetland habitats most relevant for this carbon storage include healthy mires, bogs and fens, intact salt marshes, and well-functioning riparian, fluvial and swamp forests, with peatlands holding by far the largest long-term carbon stocks (Abdul Malak et al. 2021). However, riverine and coastal wetlands, including riparian forests, floodplains and salt marshes, provide high annual sequestration rates and play a key role in short- to mid-term carbon cycling, with floodplain (riparian) forests, for example, reaching sequestration rates of up to 103–217 g C $m^{-2}$ $yr^{-1}$ (Abdul Malak et al. 2021; see Ludewig et al. 2026 for further empirical data). Crucially, human degradation, such as drainage and land conversion, can reverse wetland function, turning them from carbon sinks into $CO_2$ sources (Taillardat et al. 2020). In general, wetlands play a role in the greenhouse gas (GHG) balance beyond $CO_2$: they are sources of non-$CO_2$ greenhouse gases such as methane ($CH_4$) and nitrous oxide ($N_2O$) as a result of anaerobic decomposition of organic matter, and this production is higher than in upland ecosystems (Neubauer and Megonigal 2015). Although emitted in much smaller quantities than $CO_2$, $CH_4$ and $N_2O$ are far more potent greenhouse gases, with global warming potentials about 28–34 times ($CH_4$) and 26–298 times ($N_2O$) higher than $CO_2$ over a 100-year timescale (IPCC 2023c). Overall, net GHG fluxes in both riverine and coastal wetlands are complex and shaped by abiotic and biotic factors: hydrology, soil oxygen availability and nutrient levels interact with biotic components (microbial communities, vegetation and organic matter dynamics), thereby determining net fluxes (Mitsch et al. 2012; Zak et al. 2026). In freshwater wetlands, high water tables promote anoxic conditions, therefore boosting $CH_4$ emissions, while fluctuating or lowered water tables enhance $N_2O$ production by creating oxic-anoxic transitions. In coastal wetlands, $CH_4$ emissions are typically low because sulphate-rich tidal waters inhibit methanogenesis, and $N_2O$ emissions are mainly controlled by tidal flushing and external nitrogen inputs.

It is important to emphasise that, while wetland restoration is highlighted for its climate change mitigation potential, the conservation and restoration of riverine and coastal wetlands deliver a much wider suite of additional co-benefits (biodiversity, water quality and related services) that are substantial at the landscape scale (Jay and Plieninger 2025). For example, restoring 27% of wetlands historically drained for agriculture could reduce current nitrogen loads to the sea by 36%, while a less disruptive scenario, targeting wetlands on farmlands projected to be abandoned, would still achieve a 22% reduction (Bertassello et al. 2025).

## From knowledge to action – implications for restoration and conservation

European riverine and coastal wetlands are situated at the intersection of several environmental crises: climate change, biodiversity loss, land-use changes, exploitation of freshwater resources and pollution (Junk et al. 2012; Rodríguez-González et al. 2022; von Unger et al. 2022). They have been massively degraded over the past centuries through drainage, land-use change, pollution and fragmentation. Climate change is exacerbating these dynamics, for example, by intensifying periods of drought or accelerating the release of greenhouse gases from degraded wetlands. They are disproportionately vulnerable, as they are highly sensitive to changes in water availability, nutrient loading, chemical contamination and temperature shifts (Moomaw et al. 2018). These pressures are not only interconnected but also mutually reinforcing and pose a major challenge to ecological and social resilience. However, they can also be tackled together, as healthy floodplains and coastal wetlands have the potential to provide an integrated solution (Urbanič et al. 2022). Research findings show that functional riverine and coastal wetlands offer great potential for Nature-based Solutions (Kaden et al. 2023), with a favourable cost-effectiveness ratio precisely due to this advanced state of deterioration. Indeed, wetland restoration or recreation has measurable positive effects on biodiversity and Ecosystem Services (ES) with relatively small investments in terms of funding or land area (Thiere et al. 2009; Meli et al. 2014; Berezowski et al. 2018; Feld et al. 2018; Serra-Llobet et al. 2022). Thus, they enable cost-effective measures to restore ecosystem functions and enhance resilience to extreme weather events (see Birk et al. 2026; Stammel et al. 2026).

In recent years, the political landscape has increasingly addressed challenges of ecosystem degradation, with wetlands receiving growing attention due to their ecological significance and vulnerability. However, much of this focus has centred on peatlands because of their carbon relevance, while riverine and coastal wetlands, such as floodplains, deltas and coastal marshes, have received comparatively less attention, despite their high multifunctionality and crucial role in climate resilience. At the global level, the Ramsar Convention on Wetlands, adopted in 1971 and in force since 1975, is dedicated specifically to the conservation and sustainable management of wetlands. The Kunming-Montreal Global Biodiversity Framework, adopted in 2022 under the Convention on Biological Diversity, sets out global objectives aimed at halting biodiversity loss and restoring degraded ecosystems.

At the European level, the EU launched its new Biodiversity Strategy for 2030 as part of the European Green Deal, providing a renewed policy framework for halting biodiversity loss and promoting ecosystem restoration. The European Habitats and Birds Directives, with the Natura 2000 network, play a central role in this. Currently, 26% of the EU's land is covered by protected areas, with the target set to increase this to at least 30% by 2030. Furthermore, the EU strategy calls for strictly protecting one-third of existing protected areas and effectively managing all protected areas by setting clear conservation objectives, implementing targeted measures and monitoring their success. Key restoration measures include integrating biodiversity-rich landscape features on

agricultural land, which makes up the majority of European wetlands; halting the decline of pollinators; reducing the use and risk of pesticides by 50% by 2030; and restoring at least 25,000 km of rivers to a free-flowing state – just to name a few (see Stoffers et al. 2026).

Further strengthening the EU's legal commitment to restoration, the Nature Restoration Regulation entered into force in 2024 with binding restoration targets for degraded ecosystems, including wetlands. By 2030, Member States are required to implement restoration measures on at least 20% of the EU's land and sea areas, with the ambition to extend these efforts to all ecosystems in need of restoration by 2050 (Hering et al. 2023). The regulation focuses particularly on habitats and species covered by existing EU directives and introduces a binding, outcome-oriented implementation mechanism aimed at achieving measurable improvements across diverse ecosystem types – from wetlands and forests to rivers and urban green spaces. The central and complex challenge lies in the implementation of these goals and requires coherent action at several levels. Despite existing scientific knowledge, political strategies and legal frameworks, practical implementation is often fragmented, slow or insufficiently coordinated (e.g. Urbanič et al. 2022).

Effective implementation requires the translation of European goals into national and local strategies with clear and effective measures. Successful implementation also involves coordinating EU policies such as the EU Biodiversity Strategy, the Nature Directives, the Water Framework Directive, the Flood Directive, the Climate Strategy and the Marine Strategy Framework Directive (Pröbstl et al. 2025; Klusmann et al. 2026). However, the lack of coordination is not limited to environmental policies. Cross-sectoral cooperation is needed, for example, in collaboration with agriculture and the Common Agricultural Policy (CAP) (see Rouillard et al. 2026). Indeed, the CAP incorporates some environmental ambitions related to wetlands (e.g. buffer zones), but the mechanisms by which farmers and landowners receive rewards or compensation for sustainable practices remain unclear (Englund et al. 2021). Moreover, a good articulation between conservation and restoration versus human activities implies opening the box of what we call human activities. For example, in many floodplains and coastal ecosystems, there are substantial differences between intensive and extensive uses, with major implications for conservation and restoration strategies.

Multifunctionality can support action planning by considering the multiple dimensions and services provided by riverine and coastal wetlands (Schindler et al. 2016; Jähnig et al. 2022; Stammel et al. 2026). However, this is sometimes inconceivable at the level of individual wetlands due to trade-offs between different objectives but can be achieved at the landscape scale, where various objectives are optimised across different wetlands (Jay and Plieninger 2025). This, however, complicates management, as it involves more actors and requires strong coordination across territories and scales.

Small wetlands are often in worse condition than larger, more emblematic wetlands (e.g. Ramsar sites). They are mostly found on private land and scattered throughout the landscape, forming a dense network that is critical for achieving this landscape-scale multifunctionality. However, their private ownership adds challenges (Dufour et al. 2020). Effective conservation, management or restoration therefore requires strengthening place-based, bottom-up approaches (see Kmetova-Biro et al. 2026). Such approaches are also needed, as

the extent to which floodplains and coastal wetlands provide different functions varies considerably depending on local hydrology, landscape configuration and ecosystem type (e.g. Bullock and Acreman 2003). This means providing local managers with adequate resources, such as funding, time, technical support, clear regulations and training, to carry out ambitious plans and projects.

Therefore, understanding and dealing with people's perceptions and opinions about wetlands is also critical, as they may differ from experts' assessments and thus lead to misunderstandings between stakeholders (Cottet et al. 2013; Arsénio et al. 2019). To tackle this, it is essential to deepen research into the social dimensions of wetlands (economic, cultural and related aspects) and to train managers to move beyond solely biophysical approaches towards more holistic, socio-ecological management that incorporates co-creation, place-based and community-driven methods. This also implies (1) promoting a deep understanding of the economic determinants of the multiple pressures exerted on wetlands and (2) providing the cultural, political and financial means to work towards the removal, or reduction, of these pressures. Without this, restoration work risks becoming an endless process.

From a socio-economic perspective, restoration is not a cost factor but an investment in the future (see Macháč et al. 2026). Greater socio-economic recognition of wetlands also depends on developing widely accepted methods to economically value their Ecosystem Services (ES) such as carbon sequestration, climate regulation and flood mitigation (Čížková et al. 2011). According to estimates, every euro invested in ecosystem restoration generates multiple benefits, for example, through reduced risks, lower health costs and improved ES (e.g. between 8 and 38 euros per euro invested; EC 2021).

Monitoring and success control should not be overlooked. Robust, target-oriented monitoring systems are a prerequisite for efficient planning and implementation. Such systems form the scientific basis for impact control and evaluation, enabling the use of experience gained to further develop implementation strategies or to intervene and adapt to complex environmental conditions (see Cvijanović et al. 2026).

Admittedly, climate change poses an additional threat to European riverine and coastal wetlands, on top of historical and ongoing human impacts. However, it also offers the opportunity to develop adaptive wetland management and restore lost and degraded systems if we change our attitude towards them (Čížková et al. 2011; Rodríguez-González et al. 2022).

## Conclusion

The position of riverine and coastal wetlands at the interface of climate and biodiversity challenges demonstrates how deeply intertwined these crises are and underscores the need for integrated responses. However, we conclude by emphasising the need to clearly distinguish biodiversity loss from climate change, warning against framing them as competing issues. It is counterproductive to pit climate protection against the biodiversity crisis. Biodiversity must step out of the shadow of the climate debate, as functional ecosystems, especially wetlands, are far more than carbon sinks; they are living, complex systems possessing intrinsic and irreplaceable values beyond their utility to humans (Glaubrecht 2025).

The United Nations' biodiversity goals highlight the urgency of not only mitigating climate change but also reversing decades of biodiversity neglect. Decades of insufficient prioritisation and fragmented conservation efforts have contributed to a significant decline in global biodiversity, with many species already extinct or at risk of extinction within the coming decades (IPBES 2019). Protecting large and connected wetland areas helps preserve whole ecosystems, not just isolated species. Thus, the solution lies in giving more space back to nature through effective protection, habitat restoration and sustainable land management – approaches that must be integrated with climate strategies rather than treated as trade-offs. While climate change mitigation, such as reducing $CO_2$ emissions, is crucial, it alone cannot halt the biodiversity crisis. However, healthy, functioning ecosystems such as wetlands have the unique capacity to maintain critical Ecosystem Services while simultaneously preserving irreplaceable forms of life. Protecting connected natural areas is essential for maintaining carbon sequestration, water purification, pollination, nutrient cycling, soil stability and agricultural productivity, which benefit both nature and people.

Complementary to the global targets emphasising the expansion of protected areas, the European Union is simultaneously taking action through its Nature Restoration Regulation (NRR), which aims to restore at least 20% of degraded ecosystems by 2030 (Hering et al. 2023). By not focusing solely on protected areas but also on enhancing the ecological integrity of managed and multifunctional landscapes, including agricultural and urban zones, the NRR offers a restoration vision emphasising ecological functionality and connectivity across the entire landscape. However, a point often insufficiently implemented or prioritised is the scientific evaluation of restoration success. Robust, target-oriented monitoring systems are essential to track progress, assess effectiveness and provide the evidence base for adaptive management.

Riverine and coastal wetlands emerge as particularly strategic ecosystems and must be considered critical in all conservation and restoration strategies, as they are among the most efficient ecosystem types in terms of ES and biodiversity. Furthermore, they are cost-effective strategies, as they provide services and host biodiversity even in small areas, which is an advantage in densely populated landscapes such as those in the EU. This does not imply that other ecosystems should be neglected.

Realising this potential requires rethinking riverine and coastal wetlands as complex socio-ecological systems. This requires approaches that manage these ecosystems both as crucial human life resources and as highly diverse ecosystems. Achieving this demand combining strict protection of remaining intact wetlands, which remains challenging, especially in the absence of political will, with adaptive management practices that genuinely integrate sustainable human uses in and around wetlands, and with restoration actions co-constructed with all relevant stakeholders. Such an approach will be essential to facilitate the scaling up of efforts and the definition of shared objectives across governance levels, ensuring benefits for both humans and nature alike. Therefore, political, technical and cultural dimensions must be deeply integrated with ecological ambitions.

# Additional information

## Conflict of interest

The authors have declared that no competing interests exist.

## Ethical statement

No ethical statement was reported.

## Use of AI

No use of AI was reported.

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## Author contributions

U.S.K. and S.S. contributed to the conceptualisation and methodology of the study. Formal analysis was carried out by U.S.K., S.S., M.S. and M.V. Resources were provided by U.S.K., S.S., M.V., M.S. and S.D. The original draft of the manuscript was written by U.S.K. and S.S. All authors (U.S.K., S.S., M.V., M.S. and S.D.) contributed to the review and editing of the manuscript. Visualisation was handled by S.S. and M.V. Supervision was provided by M.S. and S.D., while project administration was managed by U.S.K., S.S. and M.S.

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## Data availability

All of the data that support the findings of this study are available in the main text.

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# Appendix 1

**Table A1.** List of habitat types (Annex I of the European Habitats Directive 92/43/EEC, reporting period 2013–2018) relevant to riverine and coastal wetlands, considered for the analyses in Box 2. The selection is based on Vanneuville et al. (2016), Januschke et al. (2023), and expert knowledge.

| EU wetland habitat type code | EU wetland habitat type |
|---|---|
| **1** | **Coastal Habitats** |
| 1110 | Sandbanks which are slightly covered by sea water all the time |
| 1120 | *Posidonia* beds (*Posidonion oceanicae*) |
| 1130 | Estuaries |
| 1140 | Mudflats and sandflats |
| 1150* | Coastal lagoons |
| 1160 | Large shallow inlets and bays |
| 1170 | Reefs |
| 1210 | Annual vegetation of drift lines |
| 1220 | Perennial vegetation of stony banks |
| 1230 | Vegetated sea cliffs of the Atlantic and Baltic Coasts |
| 1240 | Vegetated sea cliffs of the Mediterranean coasts with endemic *Limonium* spp |
| 1250 | Vegetated sea cliffs with endemic flora of the Macaronesian coasts |
| 1310 | *Salicornia* and other annuals colonizing mud and sand |
| 1320 | *Spartina* swards (*Spartinion maritimae*) |
| 1420 | Atlantic salt meadows (*Glauco-Puccinellietalia maritimae*) |
| 1340 | Inland salt meadows |
| 1410 | Mediterranean salt meadows (*Juncetalia maritimi*) |
| 1420 | Mediterranean and thermo-Atlantic halophilous scrubs (*Sarcocornetea fruticosi*) |
| 1430 | Halo-nitrophilous scrubs (*Pegano-Salsoletea*) |
| 1510 | Mediterranean salt steppes (*Limonietalia*) |
| 1530 | Pannonic salt steppes and salt marshes |
| 1610 | Baltic esker islands with sandy, rocky and shingle beach vegetation and sublittoral vegetation |
| 1620 | Boreal Baltic islets and small islands |
| 1630* | Boreal Baltic coastal meadows |
| 1640 | Boreal Baltic sandy beaches with perennial vegetation |
| 1650 | Boreal Baltic narrow inlets |

| EU wetland habitat type code | EU wetland habitat type |
|---|---|
| **2** | **Dune Habitats** |
| 2110 | Embryonic shifting dunes |
| 2120 | Shifting dunes along the shoreline with *Ammophila arenaria* (“white dunes”) |
| 2140 | Decalcified fixed dunes with *Empetrum nigrum* |
| 2150 | Atlantic decalcified fixed dunes (*Calluno-Ulicetea*) |
| 2160 | Dunes with *Hippophaë rhamnoides* |
| 2170 | Dunes with *Salix repens* ssp. *argentea* (*Salicion arenariae*) |
| 2180 | Wooded dunes of the Atlantic, Continental and Boreal region |
| 2190 | Humid dune slacks |
| 21A0 | Machairs (* in Ireland) |
| 2210 | *Crucianellion maritimae* fixed beach dunes |
| 2220 | Dunes with *Euphorbia terracina* |
| 2230 | *Malcolmietalia* dune grasslands |
| 2260 | *Cisto-Lavenduletalia* dune sclerophyllous scrubs |
| 2270 | Wooded dunes with *Pinus pinea* and/or *Pinus pinaster* |
| 2340 | Pannonic inland dunes |
| **3** | **Freshwater habitats** |
| 3110 | Oligotrophic waters (*Littorelletalia uniflorae*) |
| 3120 | Oligotrophic waters of West Med. with *Isoetes* spp. |
| 3130 | Oligo to mesotrophic waters (*Littorelletea/Isoeto-Nano*) |
| 3140 | Hard oligo-mesotrophic waters with benthic *Chara* spp. |
| 3150 | Natural euthrophic lakes (*Magnopotamion/ Hydrochachition*) |
| 3160 | Natural dystrophic lakes and ponds |
| 3170 | Mediterranean temporary ponds |
| 3180 | Turloughs |
| 3190 | Lakes of gypsum karst |
| 31A0 | Transylvanian hot-spring lotus beds |
| 3210 | Fennoscandian natural rivers |
| 3220 | Alpine rivers and herbaceous veg. along their banks |
| 3230 | Alpine rivers and ligneous veg. with *Myricaria germanica* |
| 3240 | Alpine rivers and ligneous vegetation with *Salix eleagnos* |
| 3250 | Constantly flowing Med. rivers with *Glaucium flavum* |
| 3260 | Water courses of plain to montane level (*Ranunculion)* |
| 3270 | Rivers with muddy banks *(Chenopodion rubri and Bidention)* |
| 3280 | Constantly flowing Med. rivers (*Paspalo-Agrostidion*) |
| 3290 | Intermittently flowing Med. rivers (*Paspalo-Agrostidion)* |
| 32A0 | Tufa cascades of karstic rivers in the Dinaric Alps |
| **6** | **Grassland Habitats** |
| 6120 | Xeric sand calcareous grasslands |
| 6270 | Fennoscandian lowland species-rich dry to mesic grasslands |
| 6410 | Molinia meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae)* |
| 6420 | Mediterranean tall humid grasslands of the *Molinio-Holoschoenion* |

| EU wetland habitat type code | EU wetland habitat type |
|---|---|
| 6430 | Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels |
| 6440 | Alluvial meadows of river valleys of the *Cnidion dubii* |
| 6450 | Northern boreal alluvial meadows |
| 6460 | Peat grasslands of Troodos |
| 6510 | Lowland hay meadows (*Alopecurus pratensis, Sanguisorba officinalis*) |
| 6540 | Sub-Mediterranean grasslands of the *Molinio-Hordeion secalini* |
| **7** | **Raised bogs and mires and fens** |
| 4010 | Northern Atlantic wet heaths with *Erica tetralix* |
| 4020 | Temperate Atlantic wet heaths with *Erica ciliaris* and *Erica tetralix* |
| 5140 | *Cistus palhinhae* formations on maritime wet heaths |
| 7110 | Active raised bogs |
| 7120 | Degraded raised bogs capable of natural regeneration |
| 7130 | Blanket bog (*active only) |
| 7140 | Transition mires and quaking bogs |
| 7150 | Depressions on peat substrates of the *Rhynchosporion* |
| 7160 | Fennoscandian mineral-rich springs and springfens |
| 7210 | Calcareous fens with *Cladium mariscus and Caricion davallianae* |
| 7220 | Petrifying springs with tufa formation (*Cratoneurion*) |
| 7230 | Alkaline fens |
| 7240 | Alpine pioneer formations (*Caricion bicoloris-atrofuscae)* |
| 7310 | Aapa mires |
| 7320 | Palsa mires |
| **9** | **Forest Habitats** |
| 9030 | Natural forests of primary succession stages of land upheaval coast |
| 9080 | *Fennoscandian deciduous* swamp woods |
| 9160 | Sub-Atlantic and medio-European oak or oak-hornbeam forests of the *Carpinion betuli* |
| 9170 | *Galio-Carpinetum* oak-hornbeam forests |
| 91D0* | Bog woodland |
| 91E0* | Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion, Alnion incanae, Salicion albae*) |
| 91F0* | Riparian mixed forests of *Quercus robur, Ulmus laevis* and *Ulmus minor, Fraxinus excelsior* or *Fraxinus angustifolia*, along the great rivers (*Ulmenion minoris*) |
| 92A0 | *Salix alba* and *Populus alba galleries* |
| 92B0 | Riparian formations on intermittent Mediterranean water courses with *Rhododendron ponticum, Salix* and others |
| 92C0 | *Platanus orientalis* and Liquidambar orientalis woods (*Platanion orientalis*) |
| 92D0 | Southern riparian galleries and thickets (*Nerio-Tamaricetea and Securinegion tinctoriae*) |